Summary of the First Network-Centric Sensing Community Workshop, 'Netted Sensors: A Government, Industry and Academia Dialogue'

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ABSTRACT

The MITRE Corporation recently hosted the first Netted Sensors Community Workshop in McLean, Virginia, on 24 October – 26 October 2005. The Workshop was sponsored by the Defense Advanced Research Projects Agency (DARPA), Office of the Secretary of Defense (OSD) Director of Defense Research and Engineering (DDR&E), and the National Science Foundation (NSF). The goal was to establish and sustain an annual Netted Sensors workshop that brings together Government, Industry and Academia to accelerate the development and transition of appropriate Netted Sensor technologies to solve real world problems. The workshop provided a forum focused on the application of netted sensing research and development (R&D) activities to solve existing and future Department of Defense (DoD), Intelligence Community (IC), Department of Homeland Security (DHS), and Environmental sensing problems. The Netted Sensors workshop brought together the Science and Technology (S&T) community, Industry, and Government / Military organizations to (1) share, discuss and disseminate new R&D results, (2) highlight new commercial products and technologies, and (3) identify and discuss nationally important sensing problems suitable for Netted Sensing solutions. This paper provides a summary of the presentations that were made at the workshop as well as recommendations for future workshops.

1. INTRODUCTION

The development and use of wireless sensor networks have become pervasive in the commercial world and across the missions of many Government sponsors. Netted sensors are no longer considered the unique domain of the academic community. Companies, such as Dust Networks (www.dustnetworks.com), Crossbow Technologies (www.xbow.com), and Millennial Net (www.millennialnet.com), market sensor network solutions for a variety of problem areas ranging from security and environmental monitoring to industrial process monitoring and maintenance. Application areas typically targeted by the academic community include wildlife habitat monitoring, livestock tracking, and traffic monitoring. What is unique about all of these applications has been an emphasis on data collection as opposed to information extraction and knowledge generation. These are fairly simple applications that capture a market niche for low cost sensors and supporting networks that relay sparse and infrequent data through low data-rate channels to a central processing facility for human interpretation and control.

The military is driven by other needs, including force protection and area surveillance. Here, the emphasis is on target detection, localization, classification, and entity tracking. Some potential military and Government applications are shown in Figure 1. The current military sensor platforms are moderately large, custom designed using proprietary software and hardware, and fairly expensive. Some of these systems are networked but most are stand-alone platforms. Examples include the Army REMBASS II and the Marine Corps TRSS systems. The Navy is beginning to invest in netted sensors for applications in littoral and deep-ocean monitoring.

Advances in proximity sensor technology, wireless networking, and integration of microelectronic/micromechanical components have produced small sensor systems with considerable sensing and computation capabilities. These

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capabilities include the ability to fuse data from multiple sensors of differing types. The next generation sensor networks have advanced to include autonomous ad hoc networking of static sensor platforms; currently, many research programs are actively investigating ways to network mobile sensor platforms. These next generation platforms are being commercially deployed today. Some military and Government netted sensors technologies and characteristics are shown in Figure 2.

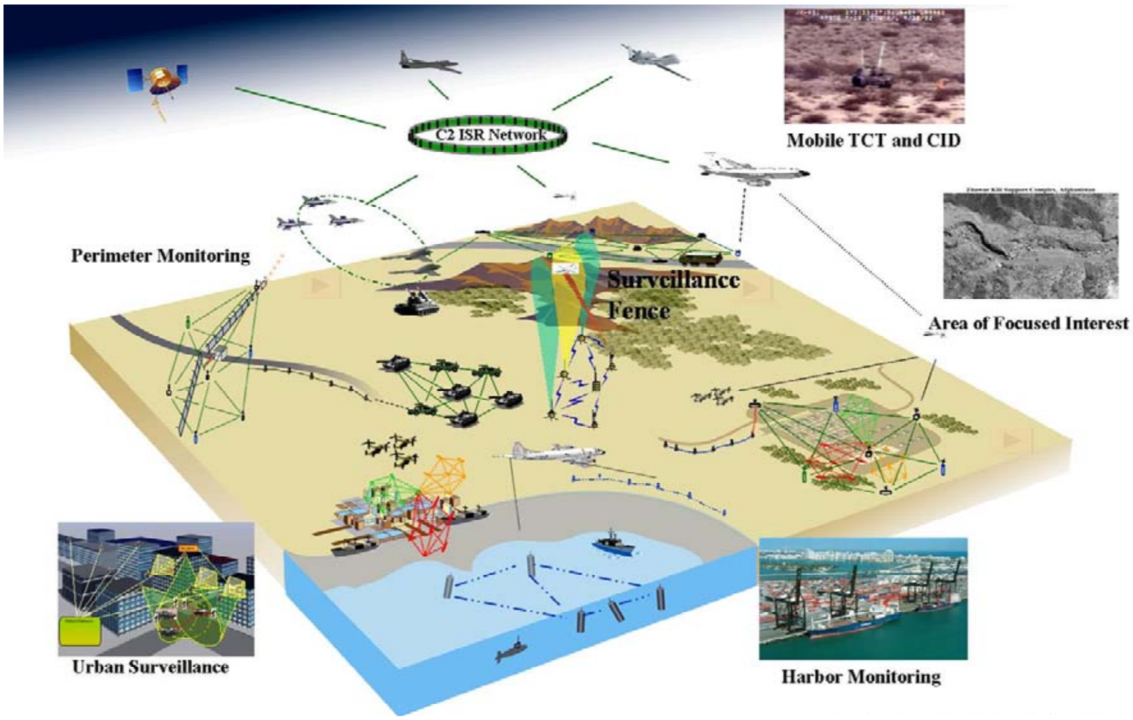

Figure 1 Some Potential Military and Government Netted Sensor Applications

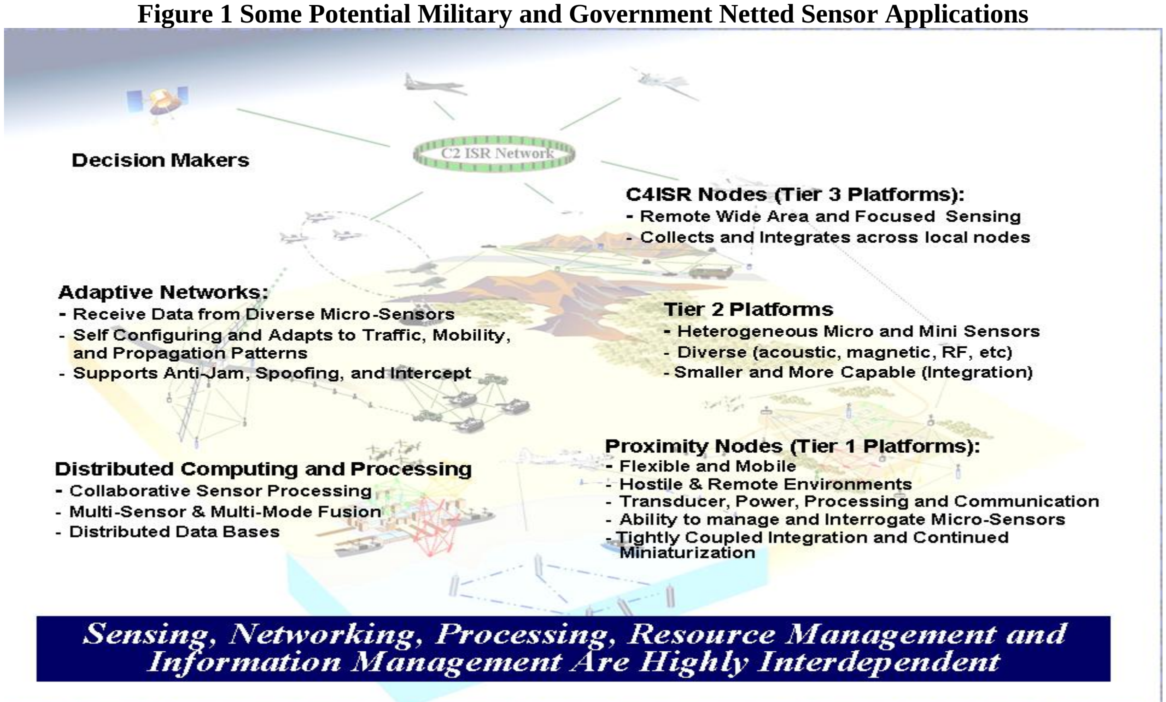

Figure 2 Military and Government Netted Sensors Technologies and Characteristics

Leveraging commercial technology investments and products with military assets to solve military-unique problems is desirable but poses several challenges. In particular, how can we combine heterogeneous in situ proximity sensors with long-range intelligence, surveillance, and reconnaissance assets?

As a result of the interest in the area of Netted Sensing by many of its military customers and its own internal R&D program in the area of Netted Sensing, the MITRE Corporation (www.mitre.org) hosted the Netted Sensors Community Workshop at its McLean, VA facilities in October 2005. The workshop was sponsored by DARPA (www.darpa.mil), OSD DDR&E (www.dod.mil/ddre), and NSF (www.nsf.gov). The goal of the workshop was to bring together Government, Industry and Academia to accelerate the development and transition of appropriate Netted Sensors technologies to real world problems. The workshop covered the latest advances in Netted Sensor R&D and commercial products as well as discussions on the applications and challenges associated with the use of Netted Sensors to solve existing and future DoD, Intelligence Community, DHS, Industrial, and Environmental problems.

2. WORKSHOP OVERVIEW

The Netted Sensors Workshop was held on 24 – 26 October 2005 at the MITRE Corporation facilities in McLean, VA. The three day workshop was divided up into nine different sessions based on topics of importance to Netted Sensing. Each session consisted of three to four talks on the session topic, usually with one talk from a military perspective, one talk from a commercial perspective, and one talk from an academic perspective. The nine sessions in the workshop were: (1) Applications and Scalability, (2) Sensors and Platforms, (3) Distributed Computing and Processing, (4) Information Management, (5) Fusion and Resource Management, (6) Information Assurance and Security, (7) Communications and Networks, (8) Environmental Monitoring and Netted Sensor Challenges, and (9) Commercial Applications and Netted Sensor Challenges. The first four sessions were held on 24 October, sessions five through seven were held on 25 October, and the final two sessions were held on 26 October.

After the completion of the talks in each session, there was a round table discussion in which all of the presenters in a given session interacted with the session chairman and the audience in a question and answer type forum.

The workshop also contained a keynote address each day, a dinner keynote address on 24 October, and daily poster and exhibit sessions where the attendees could discuss questions they had with the speakers in greater detail as well as network with each other about possible collaborative efforts.

The remainder of this paper will provide summaries of the talks in each of the sessions as well as of the keynote addresses. Workshop presentations can be found at www.mitre.org/nettedsensors.

3. SESSION SUMMARIES

3.1 Applications and Scalability Session

The Applications and Scalability session of the Netted Sensors Community Workshop consisted of four presentations that touched on a few of the many topics in this area.

3.1.1 Self-Organizing Wireless Network (SOWN)

Major James Hunsicker (Defense Intelligence Agency) and Mr. David Pitcher (The MITRE Corporation) presented a two part talk that focused on a self-organizing wireless sensor network program that was started in 2003 and the issues they faced during this program. The goal of this program was to develop an operational, rapidly deployable, environmentally rugged, robust, self-organizing autonomous sensor network. The sensor network would provide long-term, persistent surveillance of low to moderate duty cycle events resulting in detection, track, classification, and identification of vehicle and personnel targets over various types of terrain. The network would also relay resolved

actionable intelligence to operators and analysts world-wide, in a near-real time manner through a Department of Defense (DoD) national architecture that injects information into a Common Operational Picture (COP).

In the second part of the presentation, the presenters also addressed the technical challenges that are faced when making a system operational. These challenges are: (1) hardware platform durability, (2) communications, (3) sensor sensitivity, (4) target classification, (5) power management, (6) sensor concealment, (7) self-localization, (8) network security, (9) ultra-scaling of networks, (10) adaptive networks, and (11) mote mobility. The presentation also discussed investment strategies for the near (1 – 3 years), mid (3 – 5 years), and long (5 – 10 years) term to address these challenges.

3.1.2 Lessons from an "Extreme Scale" Expedition

Dr. Anish Arora (Ohio State University) presented an overview of the DARPA NEST *ExScal* experiments which deployed over 1000 motes spread over a large area in the context of a perimeter security application. The *ExScal* experiments established technical feasibility of size scaling via techniques for (i) cost effective coverage, (ii) reliable, timely, robust and accurate execution in a fabric model where lifetime where multiple applications use the same network and the lifetime of the network exceeds that of individual applications, and (iii) efficient network monitoring and application configuration/health management despite complex failure modes, environmental uncertainty, and operator error. The talk emphasized that the next challenge for scaling is the economic one, which will involve addressing how to achieve the flexibility of the software centric approach in an energy efficiency manner.

3.1.3 Networked Sensors – An Army Perspective on Future Capabilities

Dr. Derek Morris (United States Army Communications-Electronics Research, Development, and Engineering Center (CERDEC)) presented a talk that provided an overview of the many sensor networking initiatives that are currently being pursued by CERDEC along with the issues and challenges that they have encountered. The main goal of all of their efforts is focused on "soldier sensors" that address unique areas not currently being addressed by other unattended ground sensor (UGS) programs within the Army. Specifically, they are working to develop widely deployable sensors for both urban operations and wide area operations that are low cost, small, lightweight, low power, and expendable. The sensors for urban operations are focused on providing security and situational awareness while the sensors for wide area operations could fulfill a much broader spectrum of missions such as situational awareness, perimeter defense, surveillance, target acquisition, early warning of chemical, biological, radiological and nuclear (CBRN) events, and medical triage. The urban sensors would be carried and deployed by soldiers while the wide area sensors would use remote deployment mechanisms.

3.1.4 From Netted Sensors to Swarming Sensors – The Path Forward

Dr. Raja Suresh (General Dynamics Advanced Information Systems) presented a talk on a more futuristic netted sensor application, that of autonomous swarming sensors. His rationale for this vision is predicated on the fact that in the not too distant future, there will be thousands of netted ISR sensors on the battlefield and the management and control of these sensors will become a severe problem for operators to deal with. There needs to be a shift in how the sensors are controlled from the current platform based approach to a total network based approach. The big difference is that instead of each platform / sensor sending its data to an operator at a central control station for him to process and bring other sensors to bear on the target and eventually bring in assets to engage the target, the sensors and platforms work together themselves through the network to detect, track, identify, and engage the targets without human intervention. The ability to perform the mission autonomously is becoming essential in today's environment of reductions in military manpower.

3.2 Sensors and Platforms Session

The Sensors and Platforms session of the Netted Sensors Community Workshop consisted of four presentations that touched on a broad range of topics in this technology area.

3.2.1 Examples and Trends in Platforms for Ubiquitous Sensor Networks

Dr. John Suh (Crossbow Technology) presented an overview of recent progress Crossbow Technology has made in taking their sensor network platforms and supporting infrastructure from technically-focused DARPA program

applications toward market-driven commercial applications. Dr. Suh covered some of the significant challenges in commercial applications with respect to packaging, sensor networking infrastructure, platform architectures, and development and integration tools. He also highlighted the progress to overcome some of the barriers to adoption of wireless sensor networks such as reliability, lack of standardization, ease of development, and operational lifetime, all of which are equally of concern for military and Government applications.

3.2.2 ZigBee and IEEE 802.15.4 Based COTS Platforms Available Today

Dr. Robert Poor (Ember Corporation) presented a briefing on the IEEE 802.15.4 and ZigBee standards and their potential use as a means to develop multi-platform sensor networks. Dr. Poor's briefing described the similarities and differences between wireless sensor networks and wireless LANs, most notably on the need to support a variety of networking topologies and to make the most of often limited platform resources. He then focused on Ember's COTS "system on a chip" implementation of the ZigBee and 802.15.4 stacks.

3.2.3 Wireless Sensor Networks – Issues and Applications

Dr. Sokwoo Rhee (Millennial Net) presented a talk on the impact of efficient routing schemes on the scalability of ad hoc mesh wireless sensor networks, and presented a high level study of tradeoffs in approaches to increasing the communications capacity of wireless sensor networks at the physical and networking layers. He then presented a series of case studies of industrial monitoring, control, and remote sensing applications of sensor networks, highlighting the breadth of the trade space and the significant differences in platform design and enterprise integration that result.

Perhaps more importantly, this talk also highlighted the increasing divide between such commercial applications, which focus on wireless sensor networks replacing the wired data collection capabilities of existing industrial control installations, and ISR applications of interest to MITRE's sponsors, which focus on wireless sensor networks replacing the signal processing and analysis capabilities of existing ISR platforms.

3.2.4 Personal Unattended Ground Sensors

Mr. Phil Lundy (United States Army Research Development and Engineering Command (RDECOM) CERDEC Night Vision and Electronic Sensors Directorate (NVESD)) gave an overview of Unattended Ground Sensors designed for use by small units. As described in the talk, these personal UGS systems are designed for force protection, clearing, and short-term monitoring applications and are used by platoon and squad-sized units engaged in urban and asymmetric warfare operations. Mr. Lundy's talk focused in depth on the operational constraints inherent in small unit operations and their impact on potential wireless sensor network applications.

The need for soldiers to carry and hand emplace sensor systems with little time for calibration and maintenance argue strongly for lightweight, simple, robust sensor network platforms and systems, as well as for seamless integration of sensor networks into available situation awareness assets. Mission constraints imply requirements regarding network latency and bandwidth (especially exfiltration bandwidth) and operational lifetime. Logistical constraints inform requirements on the cost and reusability of sensor networks, and security constraints drive concerns of access control, LPD communications, and denial of enemy use of the deployed system.

3.3 Distributed Computing and Processing Session

The Distributed Computing and Processing Session consisted of three presentations that addressed a broad range of topics in this technology area.

3.3.1 Towards a Networked Robotic Laboratory

Dr. Gaurav Sukhatme (University of Southern California) gave a talk that outlined an emerging application area for networked robotic technology, in particular, instrumentation for field biology. Drawing from examples in aquatic and terrestrial applications, he described how networked robots could perform automated sample collection, make observations, and collect data based on varying levels of interaction with the science team. He then outlined the underlying robotic science and systems challenges that need to be met to achieve these tasks along with a report of ongoing efforts in his laboratory and the laboratories of his colleagues. Specifically, he described algorithms for three

problems: statistical network-mediated adaptive sampling using robots, network-mediated robot task allocation, and robotic network topology control. Examples of successful field deployments and the data collected were described.

3.3.2 Distributed Tracking in Sensor Networks

Dr. Chee Chong (BAE Systems Advanced Information Technologies) reviewed tracking algorithms developed for networks of large sensors and discussed the issues of tracking with small sensor networks. Target tracking is an important application for sensor networks. These issues include: resource management, communications between nodes, target association, track management, and fusion. Because of the energy and communications constraints imposed by the size of the sensors, the processing has to be distributed. He went on to discuss the challenges associated with distributing various tracking functions in multi-target tracking such as estimation and association, and surveyed the current state-of-the art in the area including suggested areas for future research.

3.3.3 Grid Technologies for Netted Sensors

Dr. Ian Foster (Argonne National Laboratory) described the three criteria for determining whether a system is a grid. First, it must coordinate resources that are not subject to centralized control. The Web is a perfect example of this – this basically highlights the contrast between a user's desktop accessing the Web for services versus central computing under local management. Sensor networks aspire to this goal but are no where near achieving this realization. Second, it must use standard, open, general-purpose protocols and interfaces. Again, the Web is a perfect example of this – it uses common protocols and interfaces and is not an application-specific system. Sensor networks are moving in this direction. For example, products by Crossbow provide a common communications and networking fabric for its motes as well as providing interface support through gateways to other equipment manufacturers' products. Third, it must deliver nontrivial qualities of service. A grid allows its constituent resources to be used in a coordinated fashion to deliver various qualities of service relative to response time, throughput, availability, and security to meet complex user demands. This is where current sensor networks are at a disadvantage. The quality of service is low in terms of latency, lost packets, throughput, and security. This necessitates driving the processing to individual sensor nodes where minimal information is conveyed across the network. For the foreseeable future, this will hamper efforts to realize the power of the network for more sophisticated applications.

3.4 Information Management Session

The Information Management session consisted of three presentations that touched on a broad range of topics in this technology area.

3.4.1 Secure Sensor Information Management

Dr. Bhavani Thuraisingham (University of Texas at Dallas) began her presentation by describing components of a secure sensor information management architecture. The central component of her architecture, the Sensor Data Manager, provides the interface to data storage components and is responsible for performing all authentication and authorization associated with data queries. As part of these functions, the Sensor Data Manger acts as the manager and enforcer of all information access and export policies.

After describing the function of the Sensor Data Manager, Dr. Thuraisingham moved on to discuss characteristics of dependable sensor information management. In short, these characteristics include fault tolerance, high integrity and assurance, and real-time processing. She pointed out that attaining these characteristics is sometimes in conflict with ensuring information security. Dr. Thuraisingham ended her presentation with a discussion of the potential value of data gathered by sensor networks for data mining applications. This is a two-edged sword in her opinion. On one hand, data feeds from sensors of different modalities and locations are possibly high value data sources for data mining algorithms. On the other hand, the ability to combine collections of data presents potential opportunities to infer information considered private from a legal or ethical standpoint.

3.4.2 Overview of IBM Technologies Relating to Netted Sensors

Mr. Paul Giangarra (IBM) presented an overview of IBM technologies related to operating a netted sensor environment. The overview included an introduction to service oriented architectures (SOA), enterprise service bus (ESB) concepts and capabilities, and a set of IBM products that facilitate ESB deployment. IBM views SOA as the current trend in the

evolution of application integration approaches. Earlier approaches include the Messaging Backbone and Enterprise Application Integration. The Messaging Backbone is characterized by point-to-point connections between applications that need to communication. Enterprise Application Integration provided application connectivity via a centralized messaging server and made it much easier to manage large numbers of connections. Systems based on SOA concepts utilize an ESB for the integration and choreography of information services. Well-defined, standards-based interfaces between information services and ESB are strongly emphasized. IBM takes the position that an ESB is a system architectural pattern as opposed to a class of software product. Functions of an ESB include message transport, transformation and routing, event handling, and web service protocol support.

IBM's view of a netted sensor environment is very broad and is not limited to a certain class or size of devices. They are applying their products to problems such as electrical system monitoring, pipeline monitoring, and asset tracking via RFID. IBM's ultimate objective is to get the data collected by sensors into the rest of the enterprise for processing, archival, reporting, etc.

3.4.3 Open Geospatial Consortium (OGC) Sensor Web Enablement (SWE) and SensorML

Dr. Mike Botts (University of Alabama at Huntsville) discussed the OpenGeospatial Consortium (OGC), its Sensor Web Enablement (SWE) activity, and the Sensor Model Language (SensorML). The Open Geospatial Consortium, Inc. (OGC) describes itself as a non-profit, international, voluntary consensus standards organization that is leading the development of open standards for geospatial and location based services. One of the initiatives of the OGC is called Sensor Web Enablement. The goal of the SWE initiative is to allow all types of Web and/or Internet-accessible sensors, instruments, and imaging devices to be accessible and, where applicable, controllable via the World Wide Web. The vision is to define and approve the standards foundation for "plug-and-play" Web-based sensor networks. The SWE defines a collection of data formats and web service interfaces that form a framework on which a sensor web can be constructed. SWE defines five specifications: SensorML, Transducer Model Language (TransducerML), Observations & Measurements (O&M), Sensor Observation Service, and Sensor Planning Service. The SensorML specification has recently been published as a Best Practices document. The TransducerML, O&M, Sensor Observation Service, and Sensor Planning Service specification are published as Discussion Papers.

In December 2005, the National Geospatial-Intelligence Agency (NGA) adopted the Open Geospatial Consortium, Inc. (OGC) web service specification baseline, along with complementary international and industry standards, as requirements for use in all NGA production processes. These standards have been inserted into the DOD Information Technology Standards Registry (DISR).

3.5 Fusion and Resource Management Session

The Fusion and Resource Management session consisted of three presentations that touched on a broad range of topics in this technology area.

3.5.1 Design of Sensor Systems with Fusion for Detection Applications

Dr. Venu Veeravalli (University of Illinois at Urbana-Champaign) talked about detection applications for wireless sensing systems and noted that detection is often a primary step in the sensing process, and in some cases the only one. He pointed out that research to date on large sensor networks has been largely focused on techniques for building sensors and protocols for networking sensors. What's missing, according to Dr. Veeravalli has been a focus on incorporating sensing / actuation into the design and optimization of wireless sensor networks for specific applications. He then talked about a core system-theoretic framework to provide guidelines for detection and fusion. He concluded his presentation with a discussion of general design principles and optimization strategies for wireless sensor networks.

3.5.2 Resource Management in Sensor Networks

Dr. David Castanon (Boston University) presented a talk that focused on recent results that address aspects of several issues that influence resource management in sensor networks. These issues included the heterogeneity of sensor networks (different power/processing/sensing capabilities in nodes), diverse excitation (the activity being sensed is not distributed uniformly), and the distribution of sensor management. The common theme to the many new ideas that are available for resource management in sensor networks is to exploit local processing. However, as Dr. Castanon pointed

out, the main limitation of these ideas is that efficient resource management requires global information about sensor status.

3.5.3 Actionable Intelligence for the Warfighter

Ms. Barbara Broome (Army Research Laboratory (ARL)) talked about the need to combine aspects of signal processing and artificial intelligence (how people think) in order to develop the new technologies that are needed to enable information exchange between the local and global worlds. Ms. Broome talked about some of the efforts that ARL is supporting that are aimed at getting actionable intelligence from the local soldiers in the field (the best place to get it) up to the Commanders as well as providing the soldiers in the field with global information pertaining to their surrounding area that they do not have access to.

3.6 Information Assurance and Security Session

The Information Assurance and Security session consisted of four presentations that touched on a broad range of topics in this technology area.

3.6.1 On the Evolution of Adversary Models in Security Protocols – from the Beginning to Sensor Networks

Dr. Virgil Gligor (University of Maryland) showed that with the introduction of each new major technology associated with computers, there was a security vulnerability identified with each within months. The problem was that it took on the order of years to develop a new model of the adversary and new methods and tools to deal with that adversary. He then went on to say that things are no different for sensor networks. The main point of his presentation was that security is a fundamental concern of secondary importance and the more could and should be done to change it into a technology concern of primary importance. Sensor network security offers such an opportunity.

3.6.2 Secure Range-Independent Localization for Wireless Sensor Networks

Dr. Radha Poovendran (University of Washington) talked about various method of determining sensor location within sensor networks including a method that did not require range information to function properly. He then talked about various ways to attack sensor networks and adversely affect the determination of sensor localization as well as the challenges faced by sensor networks in defending against these attacks. Finally, he talked about work his group has done to relate energy efficient keying to routing and network flow.

3.6.3 Challenges in Mobile Networking and Unattended Devices

Dr. Anup Ghosh (DARPA) focused his talk on the many security challenges that arise as Network Centric Warfare (NCW) attempts to move from static networks to mobile networks as well as the problems arising from the increased usage of unattended devices. Mobility will create situations, such as subnet joins, network joins, and mixed cleared/uncleared network of networks that are currently not supported, thus limiting the effectiveness of NCW. A multi-level security (MLS) process must be developed that gets away from today's slow manual process for dealing with MLS issues in order to fully take advantage of the benefits of NCW.

3.6.4 Trusted Computing and Netted Sensors

Mr. Jeffrey Leach (IBM) talked about the security protection needed by netted sensor systems from attacks from both the outside (eavesdropping and unauthorized access) and the inside (spoofing by a malicious sensor in the network, denial of service, and disturbances). He then talked about hardware-based security techniques (e.g., trusted platform modules (TPMs)) that may help secure wireless sensor networks because of their ability to provide protected, non-volatile storage, special purpose protected processing, and a spoof-resistant platform authentication capability.

3.7 Communications and Networks Session

The Communications and Networks session consisted of three presentations that touched on a broad range of topics in this technology area.

3.7.1 A Problem of Sensing in a Network Environment

Dr. Anthony Ephremides (University of Maryland) talked about cross-layer designs with application-specific character that extend from the application layer down to below the physical layer, namely the hardware so as to maximize the probability of detection using the minimum required energy. This results in an energy trade-off between processing and transmitting in which the choice of the hardware itself plays an important role. Dr. Ephremides focused on the embedded processor as the key hardware component in this trade-off. He talked about issues at three levels (the device circuit level, the microprocessor architecture level, and the compiler level) and keys to getting around these issues.

3.7.2 Cross-Layer Design for Sensor Networking

Dr. Jason Redi (BBN) provided an overview of some cross-layer methods used in DARPA's Connectionless Networks program. These methods were an end-to-end transport protocol with mid-hop operation and dynamic time synchronization. For the end-to-end transport protocol, point-to-point acknowledgements need to be used to deal with the lousy wireless bit error rates and end-to-end acknowledgements to deal with errors that point-to-point acknowledgements can't catch. Dynamic time synchronization is needed because real clocks have time drift, yet time synchronization is needed so that the radios can be turned on and off according to time slots set up for a particular network of sensors.

3.7.3 Networked Signal Processing

Dr. Anathram Swami (Army Research Laboratory) provided a review of work done in the area of signal processing for networking (channel state information, residual energy information, sensor synchronization and localization, traffic estimation and change detection, and network energy profile and density monitoring) as well as networking for signal processing (protocol design for detection estimation, and, tracking and reconstruction of correlated fields). Dr. Swami noted that scaling issues and energy constraints are critical and one cannot graft wired approaches onto a wireless medium and that it is possible that the community needs to completely rethink wireless network protocols. Dr. Swami mentioned that low duty-cycled sensor networks demand a different kind of radio and then talked about the Blue radio that ARL is developing for these types of netted sensor applications.

3.8 Environmental Monitoring and Netted Sensor Challenges Session

The Environmental Monitoring and Netted Sensor Challenges session consisted of four presentations that touched on a broad range of topics in this technology area.

3.8.1 On the Structure of Data Sets Observed by Physically Embedded Networks

Dr. Sergio Servetto (Cornell University) presented a technical discussion on estimating the structure of an unknown source from a small number of distributed sensors. This is a problem of significant interest to many netted sensing applications including environmental characterization, target classification, and even some medical applications. There are a number of issues in implementing this in a realistic environment, but Dr. Servetto showed that this is possible in certain scenarios using only a single sensor.

3.8.2 Sea Microsystems Technology (MST) Advances for Sensor Networks for Environmental and Security Monitoring

Dr. David Fries (University of South Florida) described his work in developing micro-electromechanical systems (MEMS) technology to develop novel low power sensors. He combined these sensors with commercial off the shelf (COTS) wireless network components to build a low cost wireless sensor network for the maritime environment. The sensor types included pressure, temperature, salinity, chemical, and biological sensors.

3.8.3 The Role of Optimization in Sensor Networks: Localization and Energy Aware Routing

Dr. Yannis Paschalidis (Boston University) discussed two topics: sensor localization and energy efficient routing. On localization he presented a new localization algorithm using signal strength measurements. The algorithm is based on maximum likelihood ideas that can be more accurate than standard triangulation techniques. Further, he described how to optimize the placement of Tier 2 (or clusterhead) nodes to minimize the error when self localizing the Tier 1 nodes. This requires considerable knowledge about the distribution of signal strength throughout the deployment area, but could have utility in well understood environments or in situations where some advance measurements can be taken.

The energy efficient routing discussion devised a method for optimizing the throughput and energy cost of a network routing protocol for a given network deployment. The solution is an adaptive TDMA policy which switches between several different transmissions schemes based on current throughput requirements.

3.8.4 Macro-Structure Analysis of Anticipated Market

Dr. Kenneth Parker (The MITRE Corporation) talked about netted sensing being "next generation computing" from a macro-economic viewpoint and some of the implications of this view. He closed his presentation by discussing a potential killer application for wireless sensor networks, that being computing with an unreliable power grid in emerging markets using the numerous rural villages in India as the example market.

3.9 Commercial Applications and Netted Sensor Challenges Session

The Commercial Applications and Netted Sensor Challenges session consisted of four presentations that touched on a broad range of topics in this technology area. Ease of use, ease of programming or changing function, longevity of use without user maintenance, reliability, along with security and privacy remain key issues for widespread adoption of netted sensor solutions to a wide array of problems. Rapid and secure information retrieval in delay-critical tasks is even harder. The commercial world is beginning to address these issues in its new products or in products that are being developed; specifically, security, over-the-air reprogramming, as well as power management were discussed.

3.9.1 Active Wireless Sensing and Applications in RFID-Enabled Systems

Dr. Akbar Sayeed (University of Wisconsin, Madison) discussed a concept of active wireless sensing for rapid, high-rate and energy-efficient information retrieval from a desired ensemble of sensors using a remote Wireless Information Reader (WIR). The active wireless sensing concept has two primary attributes: 1) wireless sensor nodes are "dumb" in that they have very little computational power, and 2) the WIR retrieves the desired information by interrogating and "programming" the sensor ensemble with wideband space-time waveforms. Array/directivity gain combined with distributed source channel matching is proposed as a means of obtaining energy efficiency. It is concluded that the energy-fidelity tradeoff optimization needs to consider the interplay between sensing, processing, communications and source channel matching.

3.9.2 Recognizing Behaviors in Physical Space Using Distributed Imager-Based Sensor Networks

Dr. Andreas Savvides (Yale University) described current efforts in developing a live testbed for interpreting behaviors using a wireless array of small imagers and other non-imager sensors. The technology centerpiece of the testbed is a custom design address-event architecture that offers significant advantages over legacy technologies in some domains. The address-event cameras used in the project provide ultra-low power consumption and filter redundant visual information inside the imager. This in effect simplifies computation and allows the operation of low bandwidth cameras over low bandwidth radio links. The talk described an initial approach to interpreting mobility behaviors in physical space with an imager-based sensor network. Potential applications in tactical environments include Omni-directional custom camera arrays, sensory grammars (i.e., parse sensor data to text and summaries inside the network, network reconfiguration and role assignment (automatically diffuse and reconfigure the cognitive hierarchy of the network).

3.9.3 Commercialization of Wireless Sensor Networks: Challenges and Opportunities

Mr. Mark Goodman (Crossbow Technology) gave Crossbow's perspective on the wireless sensor market and evolution. The market forecast is for a low of $500M and a high of 1.25B in FY07. Environmental, agriculture, defense and security monitoring are small markets today, building automation, asset tracking, automotive and consumer applications are predicted to be a large market opportunity for wireless sensor solutions by 2010.

3.9.4 Overview of Sun Network Sensor R&D

Dr. Dennis McLain (Sun Microsystems) covered a set of Sun's networked sensors technology developments namely; SunSPOTs (Small Programmable Object Technology), Arm7-based open sensor/actuator platform with 802.15.4 radio that allow interchangeable sensor boards, an implementation of the Squawk Java Virtual Machine (JVM) on Sun SPOTS, over-the-air reprogramming and elliptic curve cryptography for MOTES. Dr McLain indicated that MOTES

and TinyOS are good but not good enough, the MOTES are delicate platforms and hard to program, as a result Sun is developing SunSPOTs as an alternative.

3.10 Keynote Addresses

There was a keynote address each day of the workshop as well as a keynote address during dinner on the first night of the workshop.

3.10.1 DARPA Netted Sensor Programs

Dr. Ted Bially (DARPA) provided an overview of several of DARPA's netted sensor programs. Specifically, he discussed the Sensor Information Technology (SensIT), Networked Embedded Systems Technology (NEST), and Camouflaged Long-Endurance Nano-Sensors (CLENS) programs. Dr. Bially stressed the need to use the power of the network and concluded his presentation with a discussion of the various technical challenges still to be worked to make netted sensing viable: (1) power, (2) mobility, (3) auto-calibration, (4) composition, (5) mobile software, and (6) robustness.

3.10.2 Whither Sensor Networks

Dr. Vijay Ragahavan (Team for Research in Ubiquitous Security Technologies (TRUST) and the University of California, Berkeley) provided his take on sensor networks and where they are going with them. By the year 2015, he envisions embedding humans with sensors to monitor vital signs, 24/7 monitoring to prevent diseases or problems like sudden infant death syndrome (SIDS), 24/7 environmental monitoring to provide advance warnings against tsunamis, forest fires, and perhaps certain kinds of earthquakes, and tagging and tracking of worldly possessions. On the military side, he envisions routine perimeter monitoring as well as surveillance over wide areas, such as borders, routine blue force tagging and tracking, and accurate shooter location and rapid communication in real-time.

However, he discussed several challenges that need to be overcome in order to achieve his vision for 2015. These challenges include security, scalability, mobility, robustness, packaging, deployment, power and power management, a common architectural framework, and integration.

3.10.3 Statistical-Mechanical Engineering

Dr. Neil Gershenfeld (Massachusetts Institute of Technology) provided an engaging talk spanning the realm from Internet-0 techniques for waveform coding using broadband impulse response functions to statistical mechanics approaches for designing systems-of-systems. He showed that it might be possible to design large robust systems from the top down, i.e., specify the Lagrangian (an energy functional) that mimics the problem to be solved and use the mathematical structure of statistical mechanics to develop the equations describing the local interactions (nodes, links, etc.). Although not explicitly stated by Dr. Gershenfeld, it was apparent that a similar approach might be used to design a netted sensor system in the thermodynamic limit where the sensor grid is dense.

3.10.4 From Smart Dust to Reliable Networks

Dr. Kris Pister (Dust Networks and the University of California, Berkeley) reviewed the history and origins of smart dust and covered where we are today with commercialization of MOTE Technology. MOTE and TinyOS work started in 1999, efforts to put a MOTE on a chip dates back 2001. OEMs want reliability, low installation and ownership costs, no wires, >5 year battery life, no network configuration and no network management. Dr Pister concluded that the MOTE netted sensors market is real with industrial and building automation being the main commercial applications; an estimate of the market is $100M in 2006 and $500M by 2010. Finally, Dr Pister indicated that adoption of MOTES will be gated by meeting reliability and power requirements and the good news is that it has been demonstrated that those problems are solved.

4. SUMMARY

The Netted Sensor Workshop held on 24 – 26 October 2005 at the MITRE Corporations facilities in McLean, VA succeeded in bringing together Government, Industry and Academia to participate in discussions relating to the current state of Netted Sensing in many topical areas of interest to these communities.

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